

# News from KM3NeT

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**Abstract.** KM3NeT is a future research infrastructure in the Mediterranean Sea, hosting a multi-cubic-kilometre neutrino telescope and nodes for Earth and Sea sciences. In this report we shortly summarise the genesis of the KM3NeT project and present key elements of its technical design. The physics objectives of the KM3NeT neutrino telescope and some selected sensitivity estimates are discussed. Finally, some first results from prototype operations and the next steps towards implementation – in particular the first construction phase in 2014/15 – are described.

**Keywords:** neutrino astronomy, neutrino telescope, KM3NeT, research infrastructure

## 1. INTRODUCTION: KM3NET GENESIS

Neutrino telescopes to measure high-energy cosmic neutrinos as messengers for astrophysical observations have been suggested more than half a decade ago (see [1] for a detailed review of neutrino telescopes and for further references). In the mid-1990s the first instruments were in operation (Baikal, AMANDA) and demonstrated the viability of the detection principle. At the same time, it became clear from their first results and refined theoretical studies that cubic-kilometre installations will be needed to exploit the physics potential of neutrino astronomy. This led to the construction of the IceCube telescope at the South Pole, while an instrument of similar size was recommended for the Northern hemisphere to complement IceCube in its field of view [2]. In 2006–2009, the Mediterranean neutrino telescope collaborations (ANTARES, NEMO, NESTOR) have conducted a 3-year design study<sup>1</sup> to work out the design of such an instrument complying with the sensitivity and reliability requirements and within a cost frame of 200 M€ per cubic kilometre of instrumented water. In 2010, the resulting technical design was presented in [3]; at that time, various options of technical solutions were described and final decisions on technology and site(s) were still pending; a high level of cost effectiveness has been reached, with an investment volume of 220–250 M€ for 4–5 cubic kilometres of instrumented volume.

Meanwhile, after an EU-funded Preparatory Phase<sup>2</sup>, the KM3NeT Collaboration has been formally founded with a governing board, project management, an external scientific and technological advisory committee and regulations laid down in a Memorandum of Understanding that is awaiting signature. All pending decisions have been taken (see Section 2), prototype tests are in progress (Section 4) and a first phase of construction has started. (Sect. 5). Some examples of expected physics sensitivities are discussed in Sect. 3.

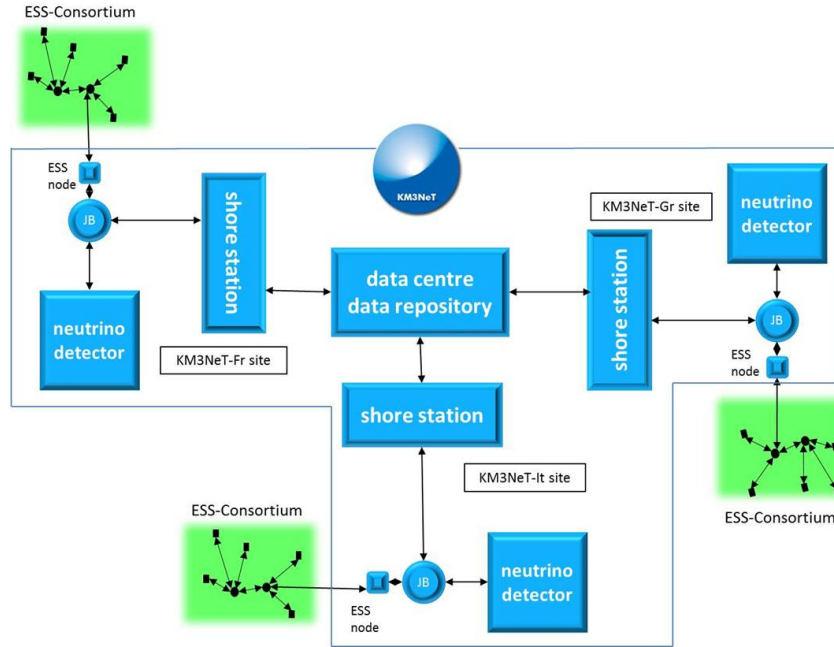
## 2. THE KM3NET TECHNICAL DESIGN

The KM3NeT research infrastructure will be constructed as a distributed installation with common detector technology, management, data handling and operation control. The installation sites will be close to Toulon, France (KM3NeT-Fr), near the East coast of Sicily, Italy (KM3NeT-It), and West of the Peloponnesus, Greece (KM3NeT-Gr) (see Fig. 1). This decision is based on detailed simulation studies indicating that – at least for muon-neutrino signals from Galactic point sources – the overall sensitivity is not reduced by splitting the detector in independent building blocks, provided these have a minimal size of about  $0.5\text{ km}^3$ . The rationale for several building blocks, as opposed to a large homogeneous detector, is both technical (related to the deep-sea cable network, power and data bandwidth requirements,

<sup>1</sup> Co-funded through the 6th Framework Programme of the EU, contract no. 011937

<sup>2</sup> 2008–2012, FP7 Grant Agreement 212525

installation/deployment issues and reliability of the detector during operation) and funding-related (to secure a significant amount of regional funding). Also, the distributed installation addresses the interest of the Earth and Sea sciences to establish a multitude of observation sites

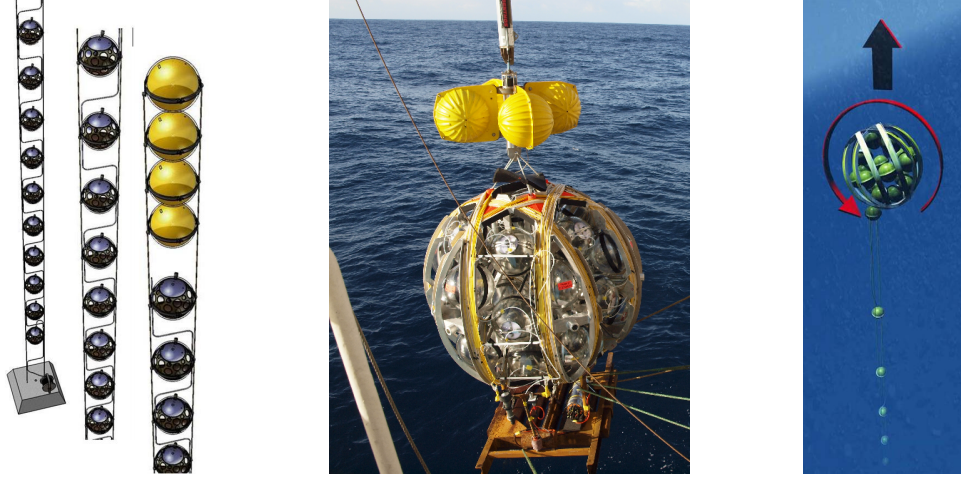


**FIGURE 1.** Schematic installation scheme for the KM3NeT research infrastructure. The KM3NeT Collaboration plans to provide nodes for the Earth and Sea Science (ESS) instrumentation but will not construct the latter.

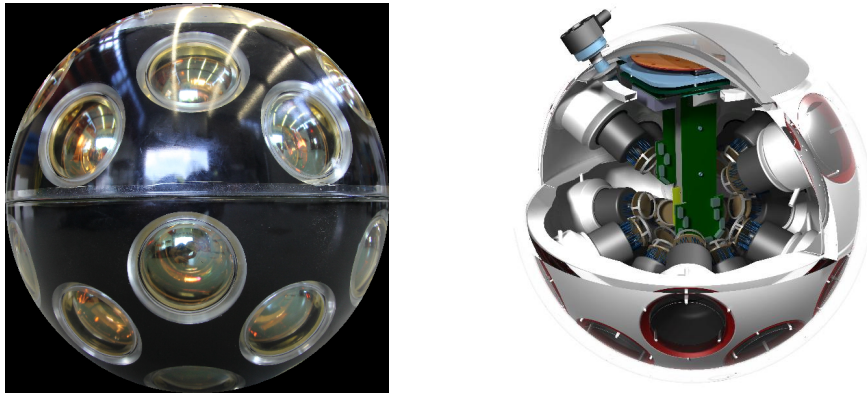
At each site, two building blocks of 115 *Detection Units (DUs)* (see Fig. 2 left) each will be constructed. The average distance between neighbouring DUs is 90 m. Each DU carries 18 *Digital Optical Modules (DOMs)*, starting 100 m above the sea floor and with 36 m distance between adjacent DOMs. The DUs are supported by two pre-stretched Dyneema<sup>®</sup> ropes and kept straight by a submerged buoy at their top. The vertical electro-optical cable (VEOC) consists of a flexible, oil-filled hose that is in equi-pressure with the sea water and contains optical fibres for data transport and copper wires for electrical power provision. For each DOM, a break-out box provides connection to one fibre and two wires. Overall, this design minimises the number of pressure transitions and allows for a slim, light-weight construction with moderate drag in sea currents. At a current of 30 cm/s, corresponding to the maximum observed at any of the installation sites, the DU top is deflected from its nominal position by about 150 m, which is well inside tolerances (note that the currents are expected to be homogeneous over the volume of one detector block).

For deployment, a DU will be wrapped on a spherical frame with about 2.2 m diameter (*Launching vehicle for Optical Modules, LOM*) [4] which is deposited on the seabed and then unfurls in a rotating upwards movement (see Fig. 2 middle and right). The LOM rises to the sea surface, where it is collected for reuse.

Each DOM (see Fig. 3) is a pressure-resistant glass sphere of 17 inch diameter that carries 31 3-inch photomultiplier tubes (PMTs) with their high-voltage bases as well as calibration devices and readout electronics. The lower hemisphere of each DOM contains 19 of the PMTs, which are thus “downward-looking”, whereas the other 12 PMTs look upwards. PMTs from two companies (Hamamatsu, ETEL) have been demonstrated to fulfil the KM3NeT specifications [5, 6] and can be produced in the required quantities in due time. The use of reflective rings around the PMT faces increases the light collection efficiency per PMT by about 27% [7]. All PMTs are controlled and read out individually. The DOM contains front-end electronics to amplify the PMT signals and to transform them into digital time-over-threshold information that is fed into the readout via optical fibres (see [8] for details on electronics and data acquisition). All PMT signals above an adjustable noise threshold (typically the equivalent of 0.3 photo-electrons) are sent to shore, where event candidates are selected by online filters running on a computer farm. The main advantages of the multi-PMT design are: (i) photocathode area per DOM increased by a factor of three as compared to optical modules with one 10-inch photomultiplier; (ii) segmented photocathode, allowing for unambiguous recognition of coincident hits and providing some directional sensitivity; (iii) reduced cost and risk due to fewer optical modules, fewer pressure transitions, and simplified mechanical structure; (iv) almost  $4\pi$  solid angle coverage by each DOM.



**FIGURE 2.** Left: Artist's view of a DU, split into 3 parts (anchor/middle/top) for presentational simplicity. The VEOC is attached in meanders along the DU to avoid tensile load and asymmetric drag in sea currents. Note that the picture is not to scale. Middle: A loaded LOM during a deployment test. Right: Upward rotational motion of the LOM during DU unfurling (picture by courtesy of Marijn van de Meer, Quest).



**FIGURE 3.** Photograph of a prototype (left) and technical drawing (right) of a KM3NeT DOM. Note that the DOM contains all front-end electronics components and also a aluminum structure for conducting the heat to the glass surface.

The time synchronisation of the DOMs at nanosecond precision is achieved by a combination of the White Rabbit [9] ethernet protocol for the shore-to-DOM communication and laser [10] and LED [11] flashers in the neutrino telescope. The position calibration of each DOM is achieved at about 10 cm precision using acoustic triangulation. The acoustic system includes transponders at the seafloor and a receiver in each DOM. These sensors use piezo elements that are integrated with the digitisation electronics and can thus be operated in electromagnetically noisy environments [12]. The DOM orientations are monitored at a few degrees using compass and tilt sensors in the DOMs.

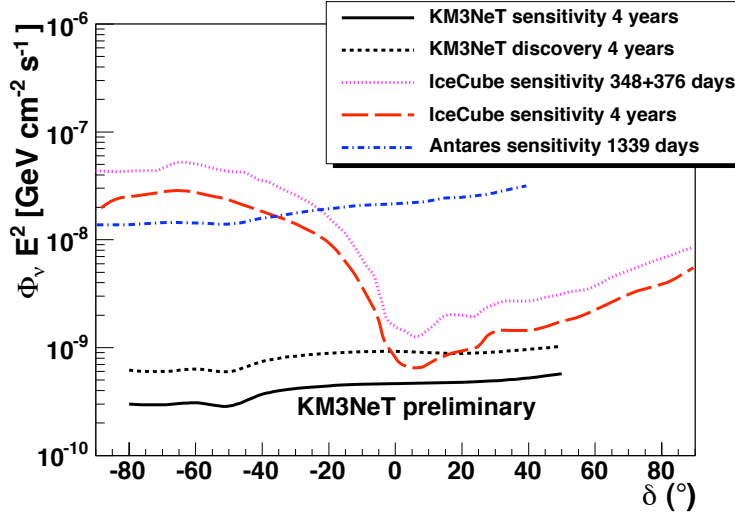
### 3. PHYSICS PERSPECTIVES

As recently impressively demonstrated by the first detection of high-energy cosmic neutrinos with the IceCube detector [13], neutrino telescopes are sensitive to neutrinos from all directions, albeit not equally for all reaction channels and energies. Detecting the muons produced in  $\nu_\mu$  charged current reactions<sup>3</sup>,  $\nu_\mu N \rightarrow \mu X$  ( $N$  being the target nucleon and

<sup>3</sup> Here and in the following,  $\nu$  is understood to denote both neutrinos and antineutrinos.

$X$  the hadronic final state), provides the best directional resolution and therefore the best prospects to identify cosmic neutrino sources. At neutrino energies up to some 100 TeV, the sensitivity for this channel is best for upward-going neutrinos; due to its location in the Mediterranean Sea, KM3NeT is therefore in an optimal position to investigate neutrino fluxes from the Southern sky, in particular from the Galactic Centre and the largest fraction of the Galactic plane.

Identifying Galactic neutrino sources is a priority physics goal with the full KM3NeT detector of six building blocks (see Sect. 2). Simulation studies [14]<sup>4</sup> show that this detector will provide a sensitivity exceeding and complementing that of IceCube for a large range in declination (see Fig. 4). Specific Galactic sources with a cut-off in their energy spectrum, as derived from high-energy gamma-ray measurements, have also been considered; it was e.g. found that the Supernova remnant RX J1713.7-3946 can be detected with  $5\sigma$  in about 5 years if its gamma-ray emission is of purely hadronic origin.



**FIGURE 4.** KM3NeT  $5\sigma$  discovery potential and sensitivity for point sources emitting a muon neutrino flux with an  $E^{-2}$  spectrum, for 4 years of data taking with the full detector configuration. The flux values are shown as function of the source declination. For comparison the corresponding sensitivities are also shown for ANTARES and IceCube (figure from [14]).

As an example of an extended emission region, the KM3NeT sensitivity to a possible neutrino flux from the “Fermi Bubbles” (two large regions above and below the Galactic Centre with a hard-spectrum gamma-ray emission detected by the Fermi satellite) has been investigated [15, 16]. Again, neutrino fluxes from these regions are readily detectable with KM3NeT if the underlying processes are hadronic and the spectrum extends up to at least 30 TeV.

Due to the focus on (Galactic) point sources, the detection of other than  $\nu_\mu$  charged current reaction channels with KM3NeT is still under study. In particular, the sensitivity to a cosmic neutrino signal as measured by IceCube [13] is expected to be reported soon.

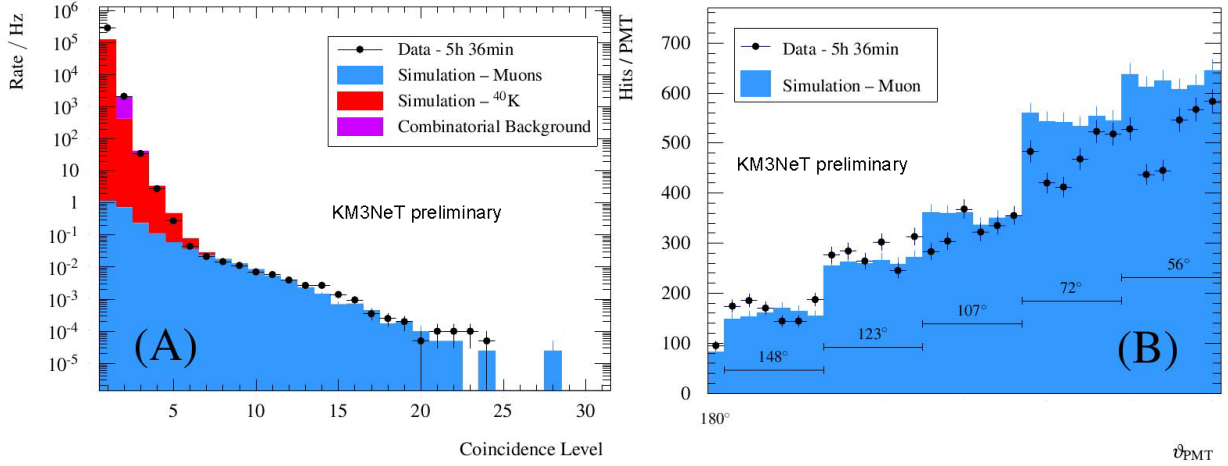
A case study is pursued by the KM3NeT collaboration on the option of employing KM3NeT technology for a dense, low-energy detector; the main objective would be a precision measurement of atmospheric neutrinos in the energy range of about 5–20 GeV and a determination of the neutrino mass hierarchy from the observed distribution of events in energy and declination (ORCA project [17, 18]).

#### 4. FIRST RESULTS FROM PROTOTYPE TESTS

Using a prototype LOM and a full-length DU with spheres, ropes and the vertical cable (VEOC), but without photo-detection or calibration instrumentation, deployment tests have been performed in April 2013. A problem with a penetrator was found and solved by redesign; various smaller issues have been identified that led to modifications of a few details of DU mechanics and LOM. Altogether the tests have clearly demonstrated that the procedure is feasible and safe, and that the DUs deployed behaved as expected (no twisting, appropriate orientation of DOMs). A further set of deployment tests with modified LOM and DU design is planned for early summer 2014.

<sup>4</sup> Note that these studies have been done for a previously considered detector configuration with two large building blocks with 310 DUs each and inter-DU distances of 100 m; the differences with respect to the 6-block configuration are, however, expected to be small.

A prototype of a KM3NeT DOM, fully equipped with photomultipliers and adapted to the ANTARES data acquisition, has been attached to an upgraded instrumentation line of ANTARES and deployed early 2013. Data taking is proceeding since April 2013. The DOM is found to be operating fully within specifications [19]. The results are in very good agreement with simulations and demonstrate the versatility of the multi-PMT concept as well as the richness and quality of information contained in the data. As an example, Fig. 5 shows the distribution of the coincidence levels (i.e. the number of PMTs with coincident signals) and the zenith angle distribution of hit PMTs in events with more than seven coincidences. It is obvious that one single DOM is able to identify muon events and to address their angular distribution, an achievement that is unthinkable for optical modules with one large PMT.



**FIGURE 5.** (A) Distribution of the coincidence levels in the prototype DOM, compared to simulation results including light from potassium-40 decays, and atmospheric muons, plus combinatorial background. Note that events with signals on more than 20 out of 31 PMTs are observed. (B) Zenith angle  $\theta_{\text{PMT}}$  of the PMT axis for those PMTs that are hit in events with more than 7 coincidences. The upward-looking PMTs observe clearly larger rates than the downward-looking ones, consistent with the angular spectrum of the muons. The discrepancies for a few PMTs at lower values of  $\theta_{\text{PMT}}$  are attributed to shadowing by mechanical structures (not yet included in the simulation). Figures taken from [19].

## 5. NEXT STEPS

The KM3NeT collaboration currently pursues the completion of the qualification tests and, in parallel, the preparation of a first construction phase at the KM3NeT-Fr and KM3NeT-It sites. As a next qualification step after the prototype DOM, a reduced-size DU with three DOMs and the final electronics will be deployed at the KM3NeT-It site to test, amongst others, inter-DOM synchronisation, readout, data acquisition and the connection to the deep-sea cable network. The deployment is expected for the first half of 2014.

According to the current planning, the production, deployment and connection of 31 DUs will take place in the period 2014 to 2016. This time scale is enforced by constraints on the availability of regional funding resources that need to be spent in accordance with EU rules. All detector components are scrutinised in *production readiness reviews* conducted by external panels in the first half of 2014. The first regular DU will be deployed at KM3NeT-Fr and will serve as a concluding engineering test. Of the remaining DUs, 24 will be deployed at KM3NeT-It to form the most sensitive neutrino telescope in the Northern hemisphere, with roughly 15–20% of the IceCube sensitivity<sup>5</sup>.

The next, intermediate objective is the construction of two full building blocks, providing a sensitivity similar to that of IceCube. This installation, which could be completed around 2017/18 if funding is secured, will have as a central physics focus the investigation of the characteristics and sources of the cosmic neutrino flux detected by IceCube.

Full KM3NeT construction (six building blocks, altogether 3–4 km<sup>3</sup>) will proceed subsequently.

Discussions are ongoing on how to include ORCA into this scenario.

<sup>5</sup> A prototype tower following the Italian “flexible tower” concept [3] has been deployed and is in operation, providing data that confirm the low bioluminescence level observed in previous measurement campaigns at the KM3NeT-It site.

## 6. CONCLUSIONS AND OUTLOOK

After about a decade of technical R&D work and simulation studies addressing the physics capabilities, the KM3NeT collaboration has converged on the technical design for the future, multi-km<sup>3</sup> KM3NeT neutrino telescope in the Mediterranean Sea. The main design concepts are the digital multi-PMT optical module (DOM); slim, flexible detection units with an equi-pressure backbone cable; their deployment on spherical structures that unfurl the DUs while “rolling up” from the sea bed. All photomultiplier tubes are read out individually; the time-over-threshold information of each PMT pulse is digitised in the DOM. Optical point-to-point connections between each DOM and shore are used for data transport and time synchronisation, allowing for sending all PMT data to shore, where they are filtered for event candidates by an online computer farm. The detector components are currently under final scrutiny, and first prototype tests in the deep sea yield very encouraging results.

KM3NeT will be constructed as a distributed research infrastructure at sites in France, Italy and Greece. Eventually, two building blocks with 115 DUs each are foreseen for each site. Operation, computing and governance are organised centrally, and the technical design of the DUs including aspects such as data acquisition and data formats is identical at these sites. At all sites, KM3NeT will provide access to real-time, continuous measurements of Earth and Sea sciences.

Currently a first construction phase at the KM3NeT-Fr and KM3NeT-It sites is funded and in preparation. A staged approach is pursued towards the completion of KM3NeT, with two building blocks as an intermediate milestone to reach an IceCube-like sensitivity.

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